



N.C. 73348

SEMICLOSED BRAYTON CYCLE POWER SYSTEM  
WITH DIRECT HEAT TRANSFER

TO ALL WHOM IT MAY CONCERN

BE IT KNOWN THAT PAUL M. DUNN, employee of the United States Government, citizen of the United States of America, resident of Wakefield, County of Washington, State of Rhode Island, has invented certain new and useful improvements entitled as set forth above of which the following is a specification:

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1 Navy Case No. 73348

2 1992

3 SEMICLOSED BRAYTON CYCLE POWER SYSTEM

4 WITH DIRECT HEAT TRANSFER

5 This patent application is copending with the related  
6 applications by the same inventor filed on the same date as  
7 subject patent entitled Closed Cycle Brayton Propulsion System  
8 ~~serial No. 07/926,116, filed 7 August 1992~~  
with Direct Heat Transfer, identified as Navy Case No. 71843,

9 ~~serial No. 07/926,090, filed 7 August 1992~~  
10 Closed Brayton Cycle Direct Contact Reactor/Storage Tank with  
Chemical Scrubber, identified as Navy Case No. 72910, Closed

11 ~~serial No. 07/926,200, filed 7 August 1992~~  
12 Afterburner, identified as Navy Case No. 72939, and Semiclosed  
13 ~~Power System~~ ~~Brayton Cycle with Direct Combustion Heat Transfer, identified as~~  
14 ~~No. 07/926,115, filed 7 August 1992~~  
~~Navy Case No. 73825.~~ ~~serial~~

15 STATEMENT OF GOVERNMENT INTEREST

16 The invention described herein may be manufactured and used  
17 by or for the Government of the United States of America for  
18 governmental purposes without the payment of any royalties  
19 thereon or therefor.

20 BACKGROUND OF THE INVENTION

21 22 (1) Field of the Invention

23 The present invention relates to a system and a process for  
24 providing power using a semiclosed Brayton cycle with direct heat  
25 transfer. More particularly the invention relates to a diesel

fueled Brayton cycle system using an inert gas as a major portion of the working fluid. This system is of particular use in torpedo and unmanned underwater vehicle propulsion systems.

(2) Description of the Prior Art

Current underwater propulsion systems are typically closed Rankine cycle power systems utilizing lithium as a fuel, a chlorofluorocarbon as an oxidant, and water as a working fluid. In a Rankine system, the working fluid is compressed, heated until vaporization, and then expanded through a turbine to produce power. Upon exiting the turbine, the low pressure vapor is condensed to a liquid, and the cycle is repeated. In a typical underwater propulsion system the working fluid is heated as it passes through heat transfer tubes that are wrapped to form a cylindrical annulus within the system's heat exchanger. The center of the cylinder contains liquid metal fuel to heat the working fluid being carried by the heat transfer tubes. The working fluid, water, and the liquid metal fuel, lithium, react chemically with one another; therefore, a leak in the heat transfer tubes causes a violent reaction which generates a significant amount of heat and gas resulting in failure of the heat exchanger and the underwater device. Furthermore, should a leak occur in a land based system, the system will release a toxic cloud of LiOH into the environment. Other problems associated with the Rankine cycle include noise generation during

1 the phase change of the working fluid, severe stress of the  
2 oxidant injectors due to high reaction zone temperatures, and  
3 slow start up time.

4 An alternative to the closed cycle Rankine power system is a  
5 closed or semiclosed Brayton cycle system. In a Brayton cycle,  
6 there is no phase change and accordingly, no noise associated  
7 therewith. The Brayton cycle is also more efficient than the  
8 Rankine cycle despite the fact that more energy is required to  
9 compress a gas than to pump an equivalent mass of liquid. Prior  
10 art Brayton cycle systems cannot be used in underwater systems  
11 because the components of the Brayton cycle, principally the  
12 conventional Brayton heat exchanger, will not fit in the  
13 restricted space available in underwater vehicles.

14 A compact heat exchanger can be made by increasing gas  
15 velocity through the heat exchanger to achieve higher heat  
16 transfer coefficients; however, this results in greater heat  
17 exchanger pressure drop. Increasing gas velocity is used  
18 successfully in Rankine cycle systems because pump power is a  
19 small fraction of gross power (1/50) and pump losses are small by  
20 comparison. Accordingly, there is no significant reduction in  
21 cycle efficiency. In the Brayton cycle, however, compressor  
22 power is typically a large part of the gross power (1/2);  
23 therefore, small increases in gas velocity and heater pressure  
24 drop reduce the Brayton cycle efficiency below that of the  
25 Rankine cycle.

1 My other listed inventions with which this application is  
2 copending relate to direct contact closed Brayton cycle power  
3 systems using liquid metal fuel. The size and weight penalty of  
4 the Brayton's hot side heat exchanger is eliminated by direct  
5 contact heat transfer between the working fluid which is an inert  
6 gas such as helium, argon, xenon, or a mixture of inert gases,  
7 and a liquid metal bath of a material such as lithium, sodium,  
8 potassium, aluminum, magnesium, or an alloy.

9

10 SUMMARY OF THE INVENTION

11 Accordingly, it is a general purpose and object of the  
12 present invention to provide an improved Brayton cycle power  
13 system. A further object of this invention is that the system be  
14 compact and capable of higher power densities than the molten  
15 metal versions and have the added advantage of burning a  
16 hydrocarbon fuel with oxygen.

17 These and other objects are accomplished with the present  
18 invention by providing a semiclosed system utilizing a Brayton  
19 cycle. In this invention, combustion occurs in a combustor  
20 between diesel fuel and O<sub>2</sub> with an inert gas present. During  
21 combustion, a heated high pressure working fluid of steam, CO<sub>2</sub>,  
22 and inert gas is formed. The heated working fluid is expanded in  
23 a turbine and then used in a regenerator to heat the cooler,  
24 compressed working fluid before this fluid is transferred to the  
25 combustor. The expanded working fluid is mixed with seawater

causing the steam within the expanded working fluid to condense to water. The CO<sub>2</sub> is dissolved in the water and seawater, and the inert gas is separated from the other components. The inert gas is recycled within the system, and the water, seawater, and CO<sub>2</sub> solution is pumped overboard.

### BRIEF DESCRIPTION OF THE DRAWINGS

A more complete understanding of the invention and many of the attendant advantages thereto will be readily appreciated as the invention becomes better understood by reference to the following detailed description when considered in conjunction with the accompanying drawings wherein:

FIG. 1 shows a diagram of a semiclosed Brayton cycle with direct heat transfer in accordance with the present invention.

## DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to FIG. 1 there is shown a semiclosed Brayton cycle power system 10. System 10 has a storage tank/sePARATOR 12 initially containing an inert gas 12a. Preferably, the inert gas is argon; however, the gas can also be a mixture of helium and xenon. The inert gas is compressed in a compressor 14 and transported to a regenerator 16 wherein the gas is partially heated. Upon exit from regenerator 16 the partially heated gas is mixed with oxygen from O<sub>2</sub> source 18 by mixing valve 20. The resulting gas mixture is transported to a combustor 22. Diesel fuel from diesel fuel tank 24 is also transported to combustor 22.

1 via diesel fuel control valve 25. Combustion of diesel fuel and  
2 oxygen occurs in combustor 22 by conventional means. The diluent  
3 inert gas mixed with oxygen acts to reduce the combustion  
4 temperature and prevent damage to combustor 22. Combustion  
5 results in the formation of a steam, CO<sub>2</sub>, and hot inert gas  
6 working fluid. The steam/CO<sub>2</sub>/inert gas working fluid is  
7 communicated to a turbine 26 where the working fluid is expanded  
8 driving output shaft 28. Output shaft 28 is mechanically  
9 connected to drive compressor 14 and auxiliary compressor 30.  
10 Shaft extension 28a allows power to be withdrawn from system 10.  
11 The mechanical connection between turbine 26 and auxiliary  
12 compressor 30 is symbolically shown by dashed line 31. The  
13 steam/CO<sub>2</sub>/inert gas working fluid after being expanded in turbine  
14 26 is routed to regenerator 16. The remaining heat from the  
15 working fluid mixture is used to preheat the inert gas as  
16 mentioned previously. Regenerator 16 operates by conventional  
17 means. There is no direct contact in the regenerator 16 between  
18 the inert gas from the compressor 14 and the working fluid  
19 mixture of steam/CO<sub>2</sub>/inert gas. The steam/CO<sub>2</sub>/inert gas working  
20 fluid is then transmitted to a spray cooler/condenser 32 and  
21 cooled by direct contact with large amounts of cold seawater.  
22 Spray cooler/condenser 32 is a constant enthalpy cooler providing  
23 a large amount of shearing and mixing between the working fluid  
24 and the seawater to promote dissolution of the CO<sub>2</sub> and  
25 condensation of the steam. The seawater, water, CO<sub>2</sub> and inert  
26 gas mixture is then routed to storage tank/separator 12. The

1 fluid components 12b, water and seawater with CO<sub>2</sub> dissolved  
2 therein, are allowed to settle to the bottom of storage  
3 tank/separator 12 where they can be pumped overboard by a  
4 seawater discharge pump 34. The remaining gas 12a, mostly inert  
5 gas with a trace of CO<sub>2</sub>, is routed back to compressor 14 inlet.

6 As with any Brayton propulsion system speed and power are  
7 regulated by adding or removing mass from the system. Auxiliary  
8 compressor 30 is available to remove the inert gas from  
9 compressor 14 discharge and forward the inert gas to an  
10 accumulator 36 through an accumulator input valve 38. Inert gas  
11 can also be added to the system from accumulator 36 through an  
12 accumulator output valve 40 to compressor 14. For most power  
13 levels and depths of operation, auxiliary compressor 30 will not  
14 be brought into operation.

15 There has therefore been described a new direct contact  
16 Brayton power system that utilizes an inert gas. Because of its  
17 use of hydrocarbon fuel, torpedo room refueling of a recovered  
18 underwater vehicle is possible. Eliminating the liquid metal  
19 fuels of previous designs reduces environmental hazards and  
20 increases community acceptance. This approach has the advantage  
21 of high power levels since both the heating and cooling processes  
22 are via direct contact. The direct contact combustion of diesel  
23 fuel and O<sub>2</sub> is a highly developed low risk technology. Very high  
24 temperatures are now easily achieved resulting in improved cycle  
25 efficiency.

1 . . . An alternate method of start up requiring slight alterations  
2 is by blowdown of the accumulator 36 to the turbine 26 rather  
3 than blowdown of storage tank/separator 12 in the preferred  
4 embodiment. The transient response of the present system is much  
5 improved over those previously designed.

6 It will be understood that various changes in the details,  
7 materials, steps and arrangement of parts, which have been herein  
8 described and illustrated in order to explain the nature of the  
9 invention, may be made by those skilled in the art within the  
10 principle and scope of the invention as expressed in the appended  
11 claims.